Electroweak Dumbbells and their dynamics

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Background

EW Monopoles & Strings

G. ’t Hooft, Nucl. Phys. B 79, 276 (1974).
A. M. Polyakov, JETP Lett. 20, 194 (1974).

Monopoles in the SO(3) Higgs model

H. B. Nielsen and P. Olesen, Nucl. Phys. B 61, 45 (1973)

String solution in Abelian Higgs model

Y. Nambu, Nucl. Phys. B 130, 505 (1977).

Physical SU(2)xU(1) model

The Weinberg-Salam theory of electromagnetic and weak interactions admits classical configurations in which a pair of magnetic monopoles is bound by a flux string of the Z^0 field. They give rise to Regge trajectories of excitations with a mass scale in the TeV range.

Our work

- Distribution of monopole-antimonopole pairs.

T.P & T.V, *JHEP*, *2022*(1), pp.1-14. (arXiv:210805357)

- Static configurations of electroweak dumbbells

T.P & T.V, *PRD* 107.9 (2023): 093010 (arXiv:2303.04886)

Ongoing

- Dynamics of rotating electroweak dumbbells
- Cosmological magnetogenesis from EWPT

Static Configuration

Monopole Antimonopole

$$\Phi_{\mathrm{m}} = \begin{pmatrix} \cos(\theta_m) \\ \sin(\theta_m)e^{i\phi} \end{pmatrix}, \Phi_{\bar{\mathrm{m}}} = \begin{pmatrix} \sin(\theta_{\bar{m}}) \\ \cos(\theta_{\bar{m}})e^{i\phi} \end{pmatrix}$$

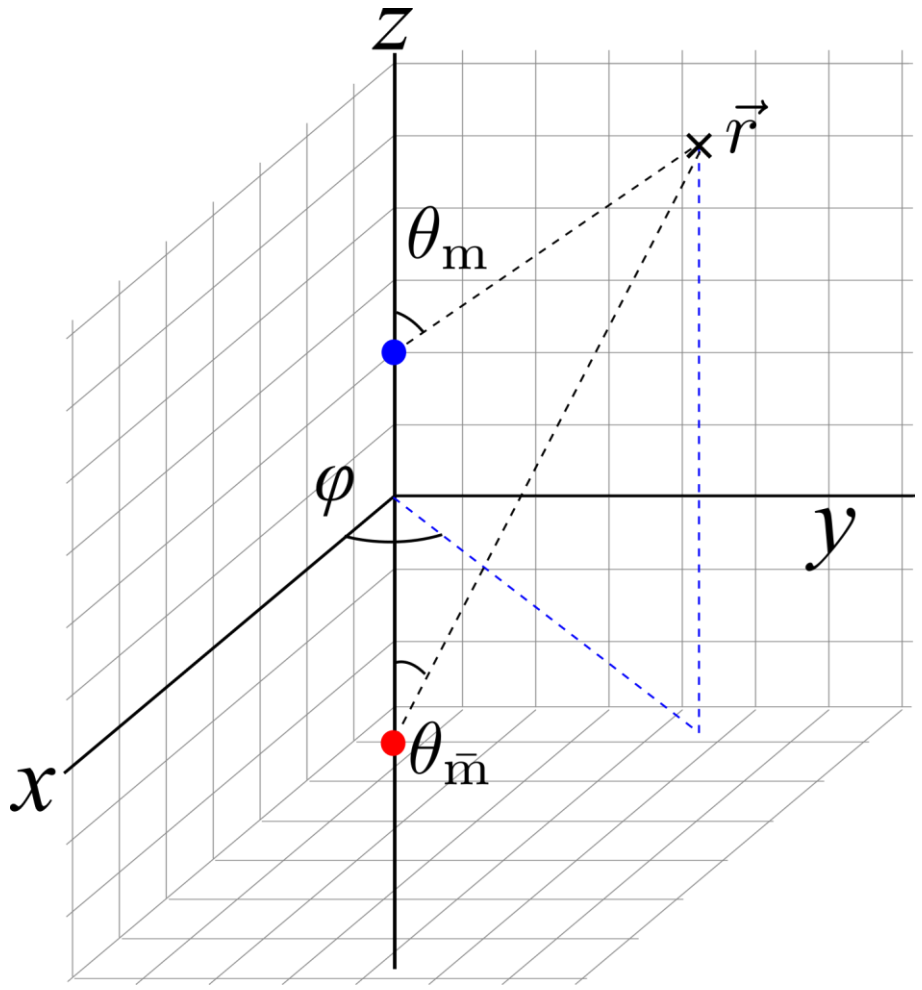
Y. Nambu, Nucl. Phys. B 130, 505 (1977).

Monopole-Antimonopole Configuration

$$\hat{\Phi}_{m\bar{m}}(\gamma) = \begin{pmatrix} \sin\left(\frac{\theta_m}{2}\right)\sin\left(\frac{\theta_{\bar{m}}}{2}\right)e^{i\gamma} + \cos\left(\frac{\theta_m}{2}\right)\cos\left(\frac{\theta_{\bar{m}}}{2}\right) \\ \sin\left(\frac{\theta_m}{2}\right)\cos\left(\frac{\theta_{\bar{m}}}{2}\right)e^{i\phi} - \cos\left(\frac{\theta_m}{2}\right)\sin\left(\frac{\theta_{\bar{m}}}{2}\right)e^{i(\phi-\gamma)} \end{pmatrix}$$

Novel Parameter: Twist γ

Vachaspati, T. and Field, G.B., 1994.
Electroweak string configurations with baryon number. Physical review letters, 73(3), p.373.



Static Configuration

The Higgs Configuration profile

$$\Phi_{\mathrm{m}\bar{\mathrm{m}}} = k(\vec{x})h(r_m)h(r_{\bar{m}})\hat{\Phi}_{m\bar{m}}$$

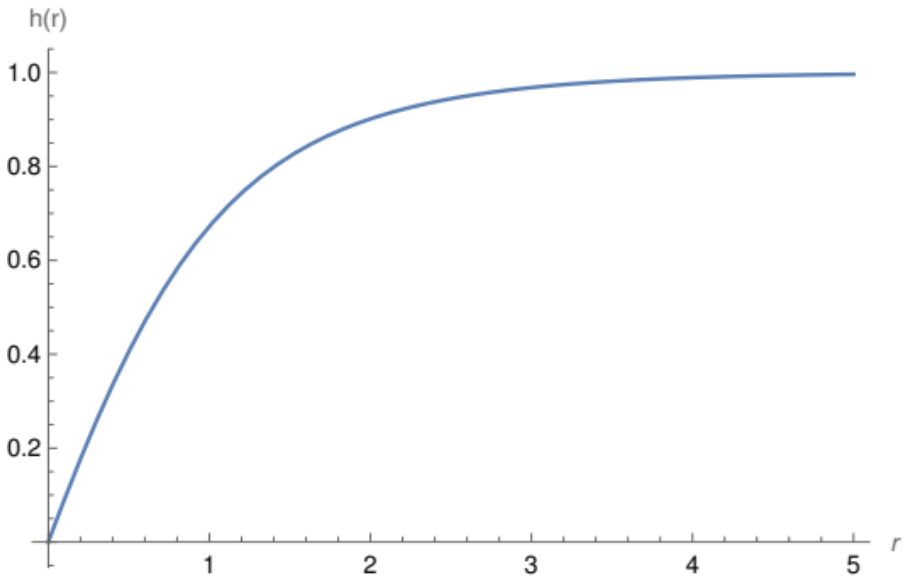
h : Monopole profile

k : String profile

Bosonic EW Lagrangian $\mathcal{L} = -\frac{1}{4}W^a_{\mu\nu}W^{a\,\mu\nu} - \frac{1}{4}Y_{\mu\nu}Y^{\mu\nu} + |D_\mu\Phi|^2 - \lambda(|\Phi|^2 - \eta^2)^2\,,$

- Fix Higgs configuration throughout
- Use guess initial profiles
- Use numerical relaxation

Initial Guess Profiles

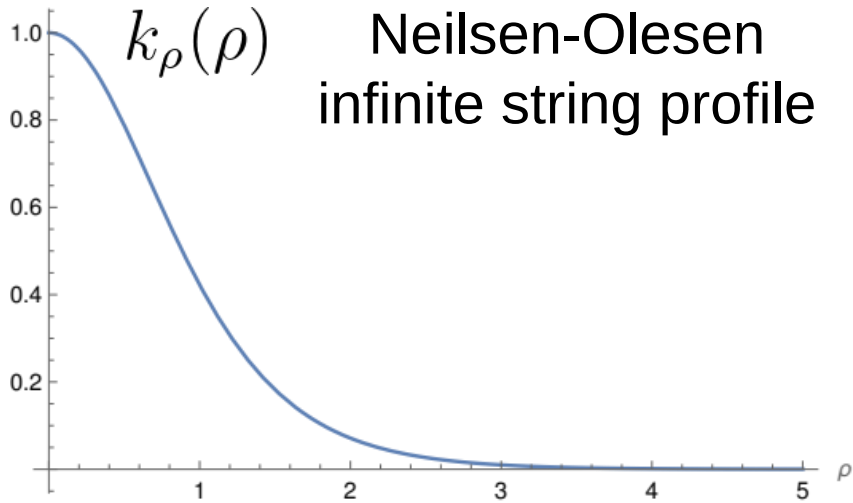


‘t Hooft-Polyakov monopole radial profile

String profile

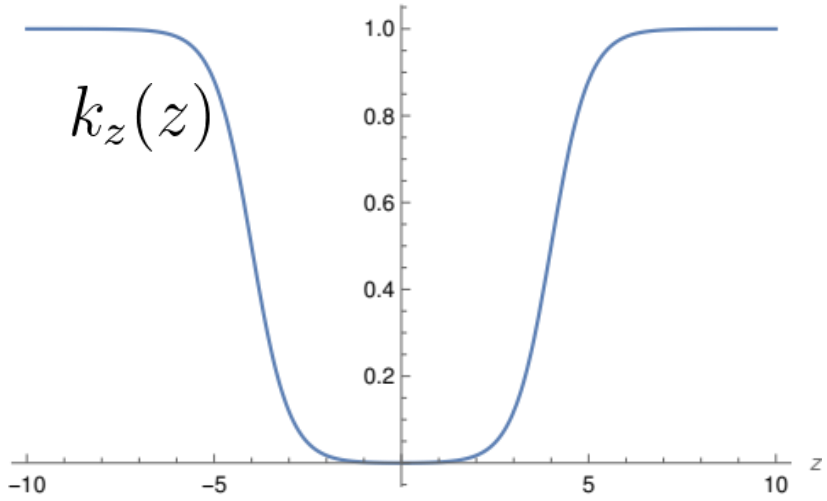
$$1 - k_\rho(\rho) k_z(z)$$

Cylindrical profile



Neilsen-Olesen infinite string profile

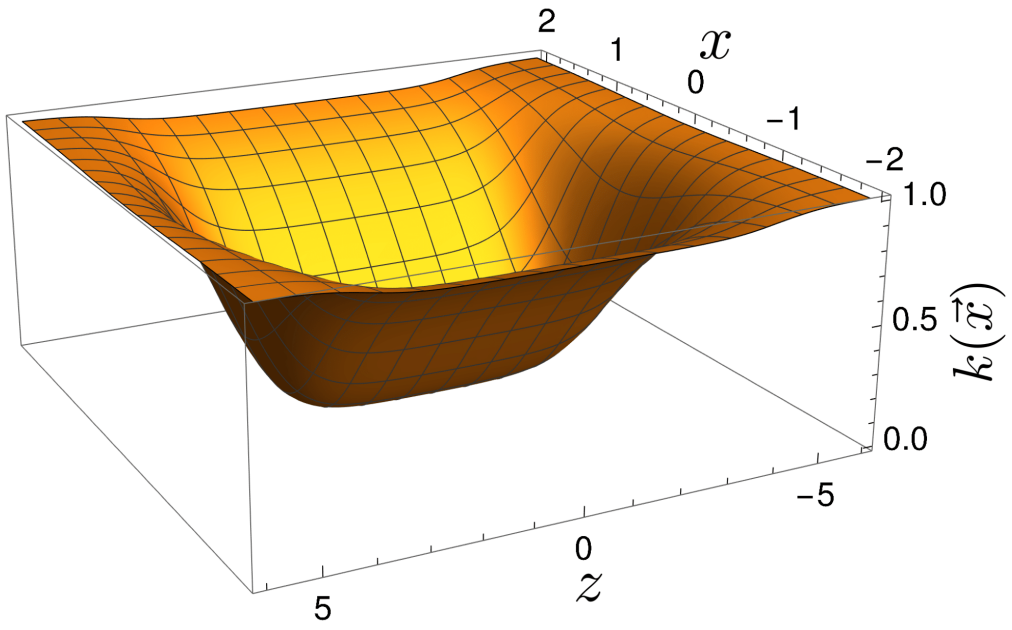
z-cutoff



Initial Guess profile

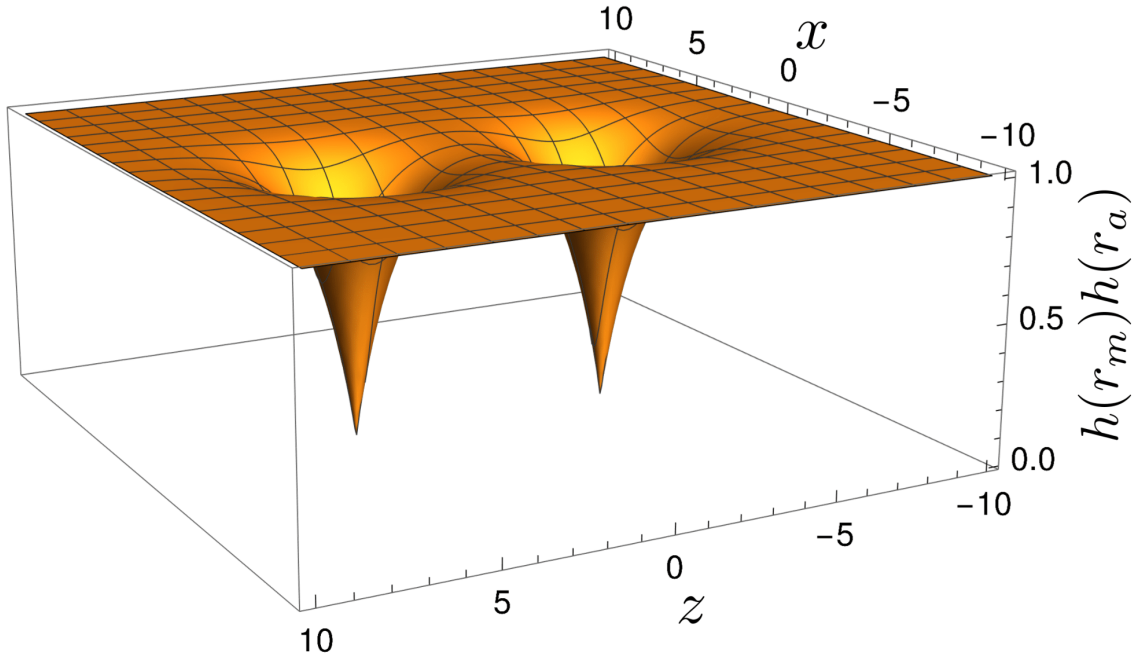
String profile

$$1 - k_\rho(\rho)k_z(z)$$

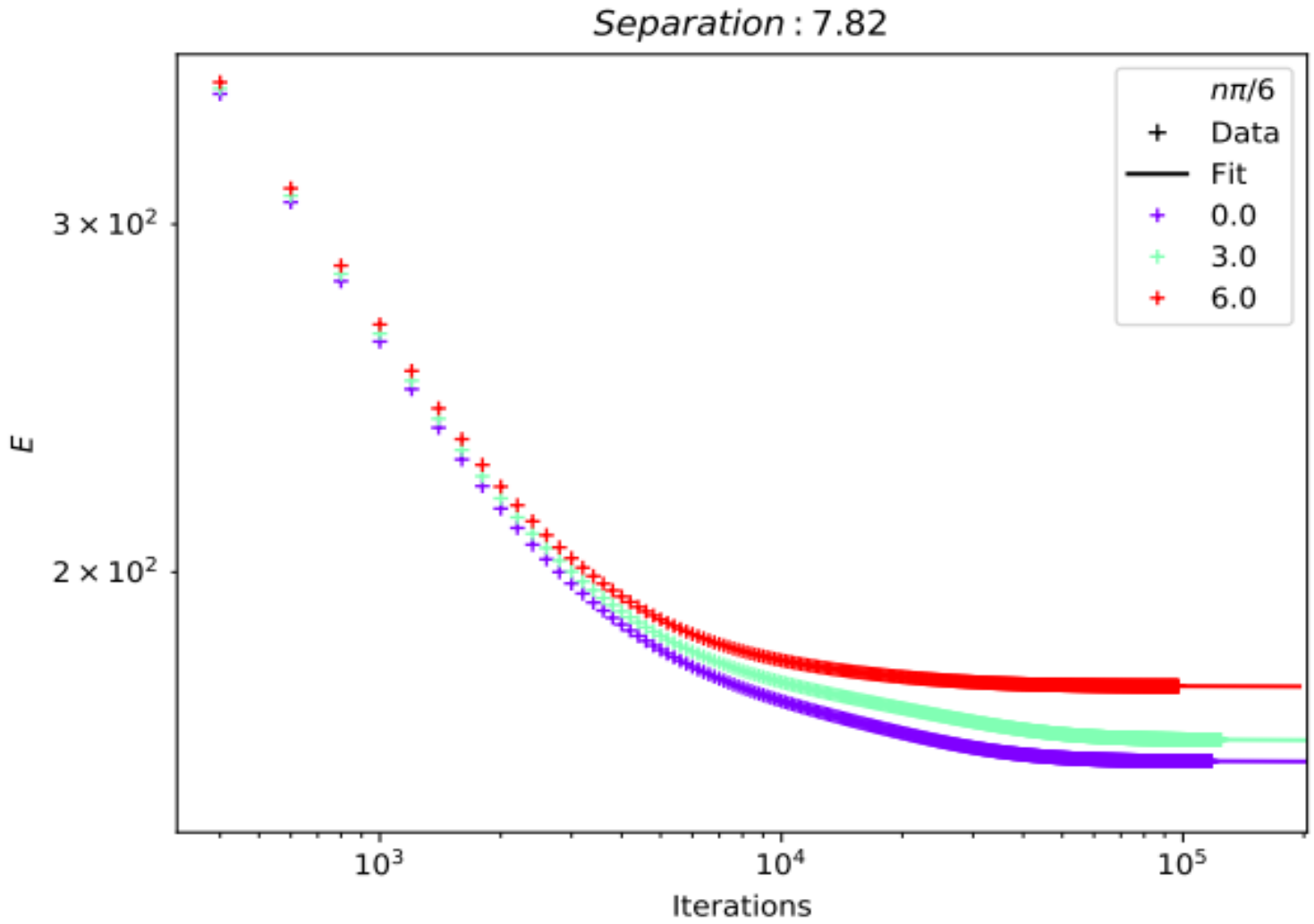


Monopole-Antimonopole profile

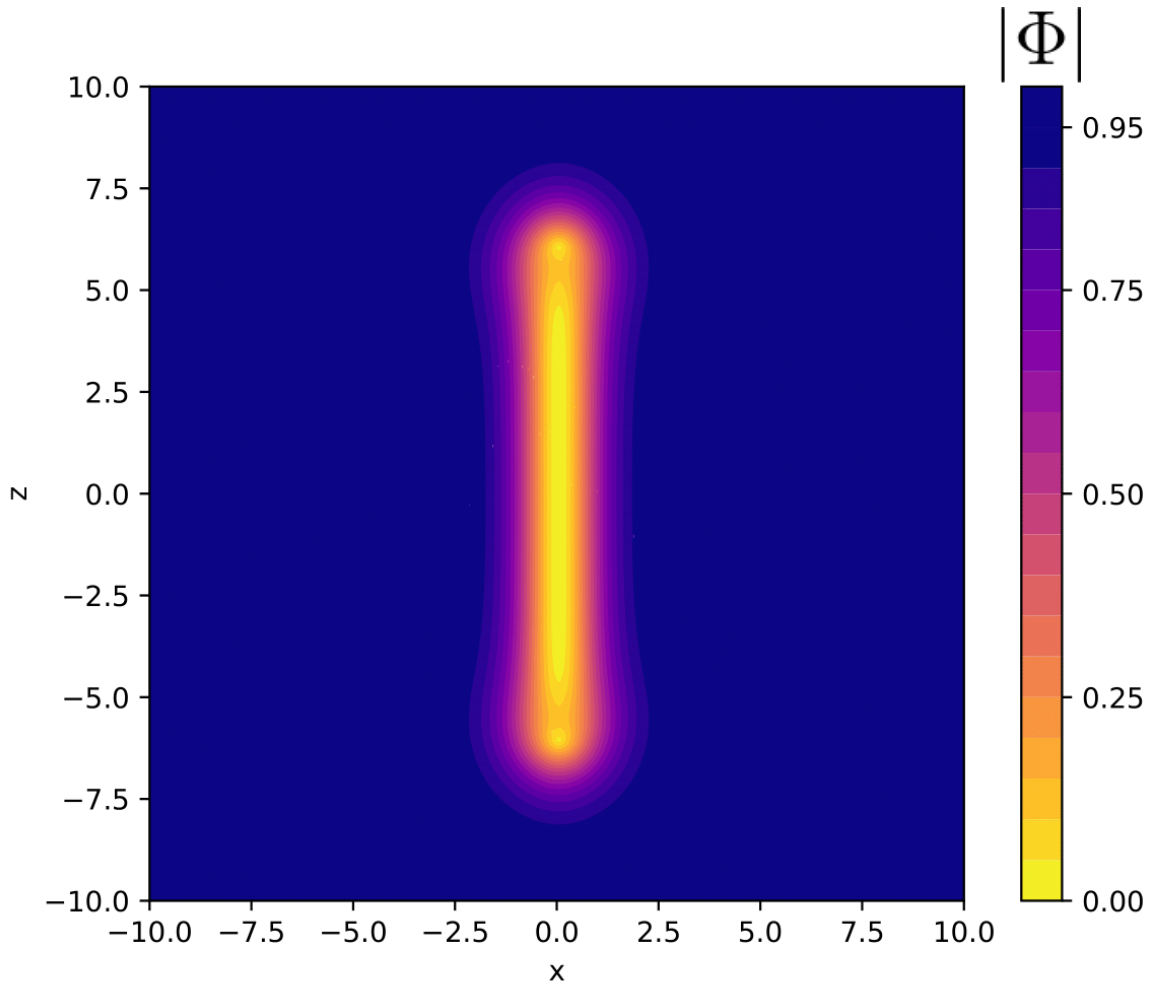
$$h(r_m)h(r_{\bar{m}})$$



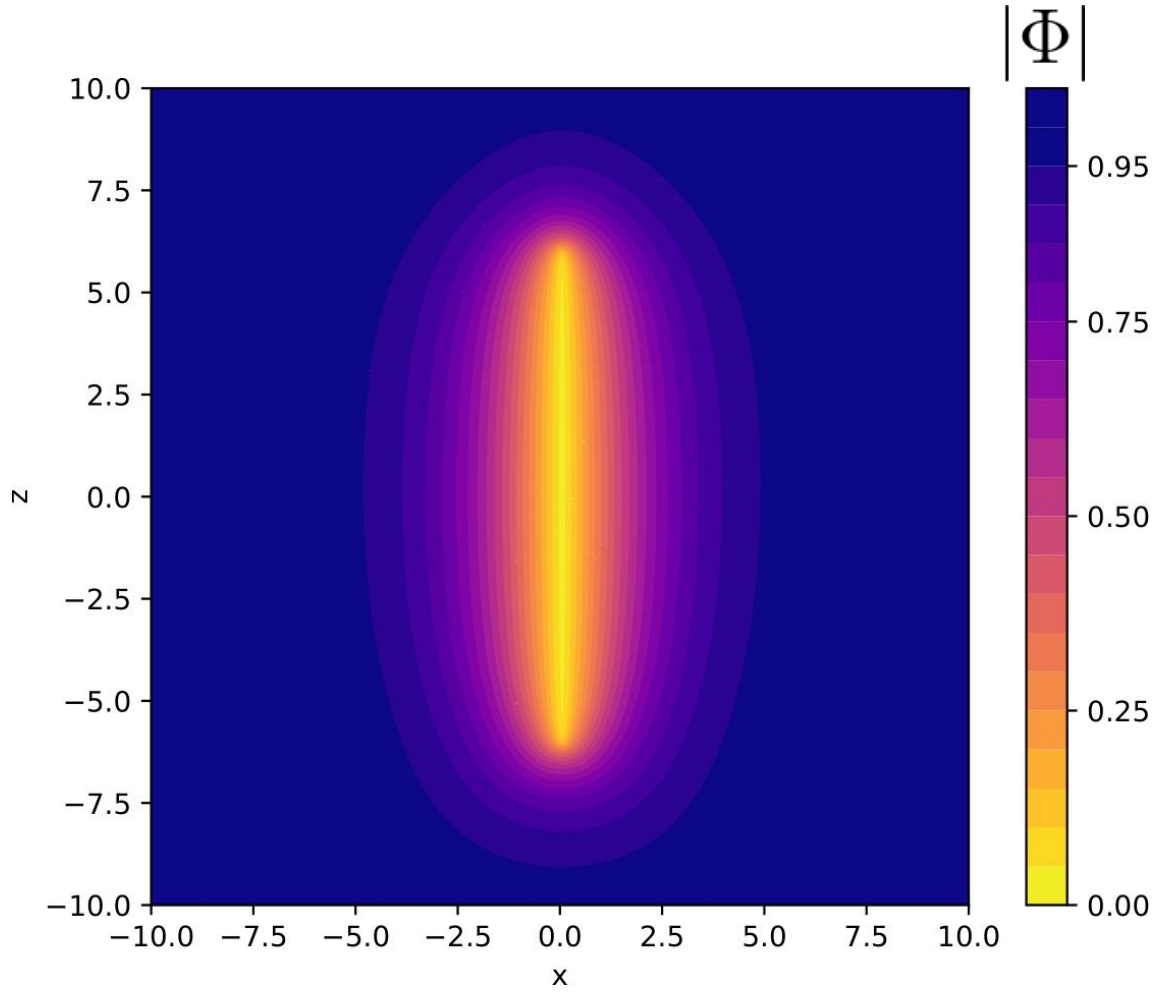
Numerical Relaxation



Results

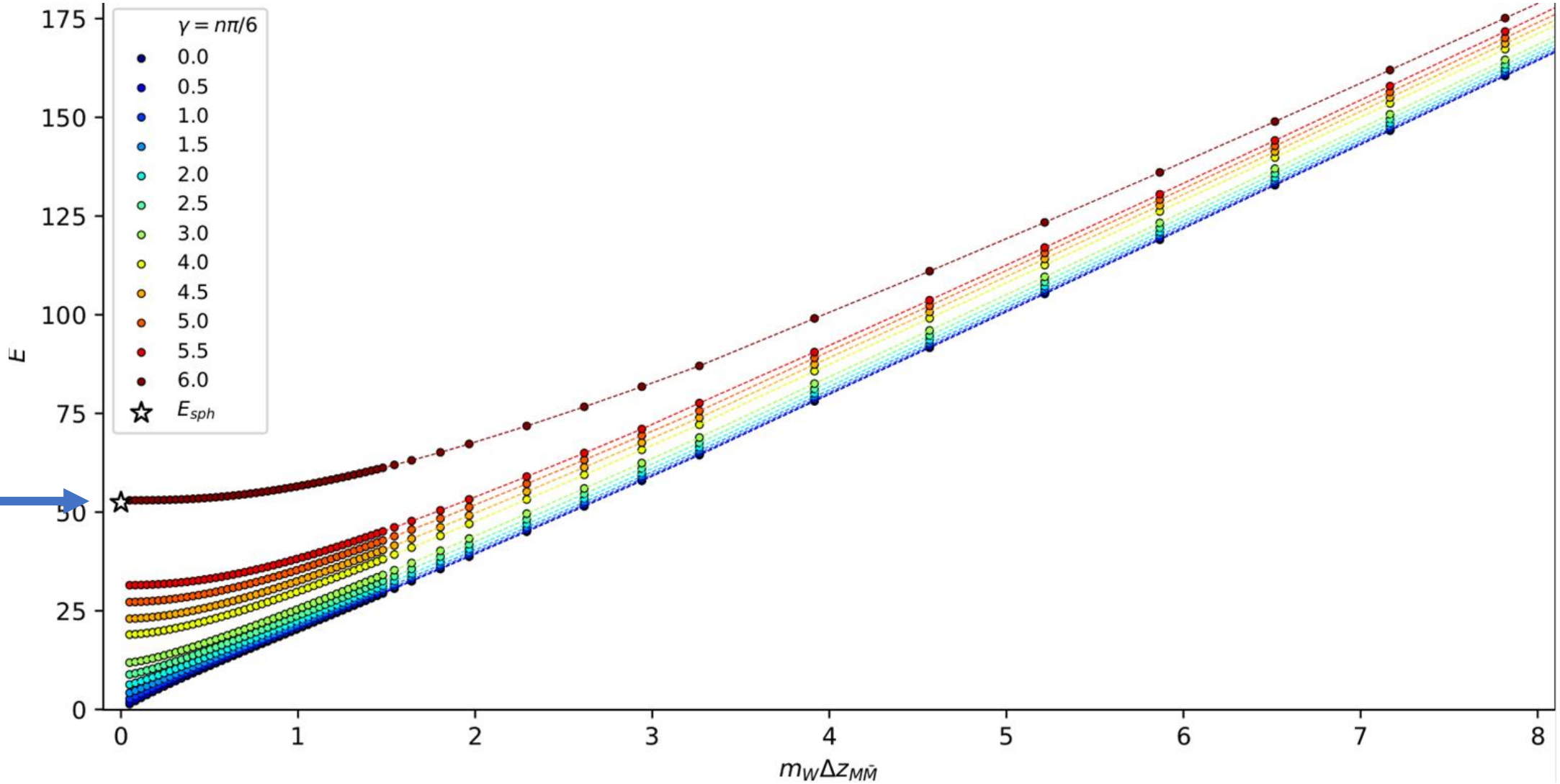


Initial Guess



Relaxed

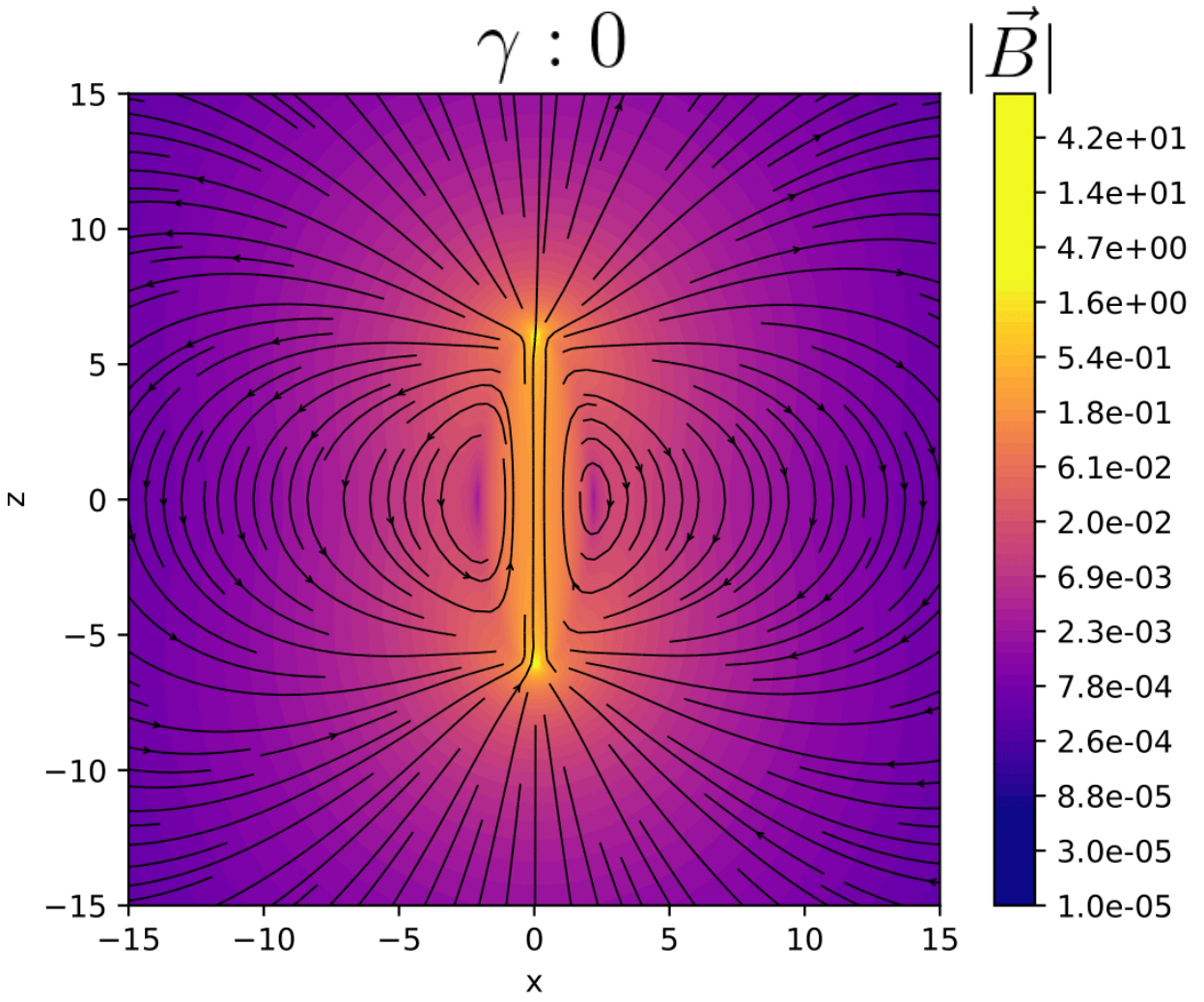
Results: Energy v separation

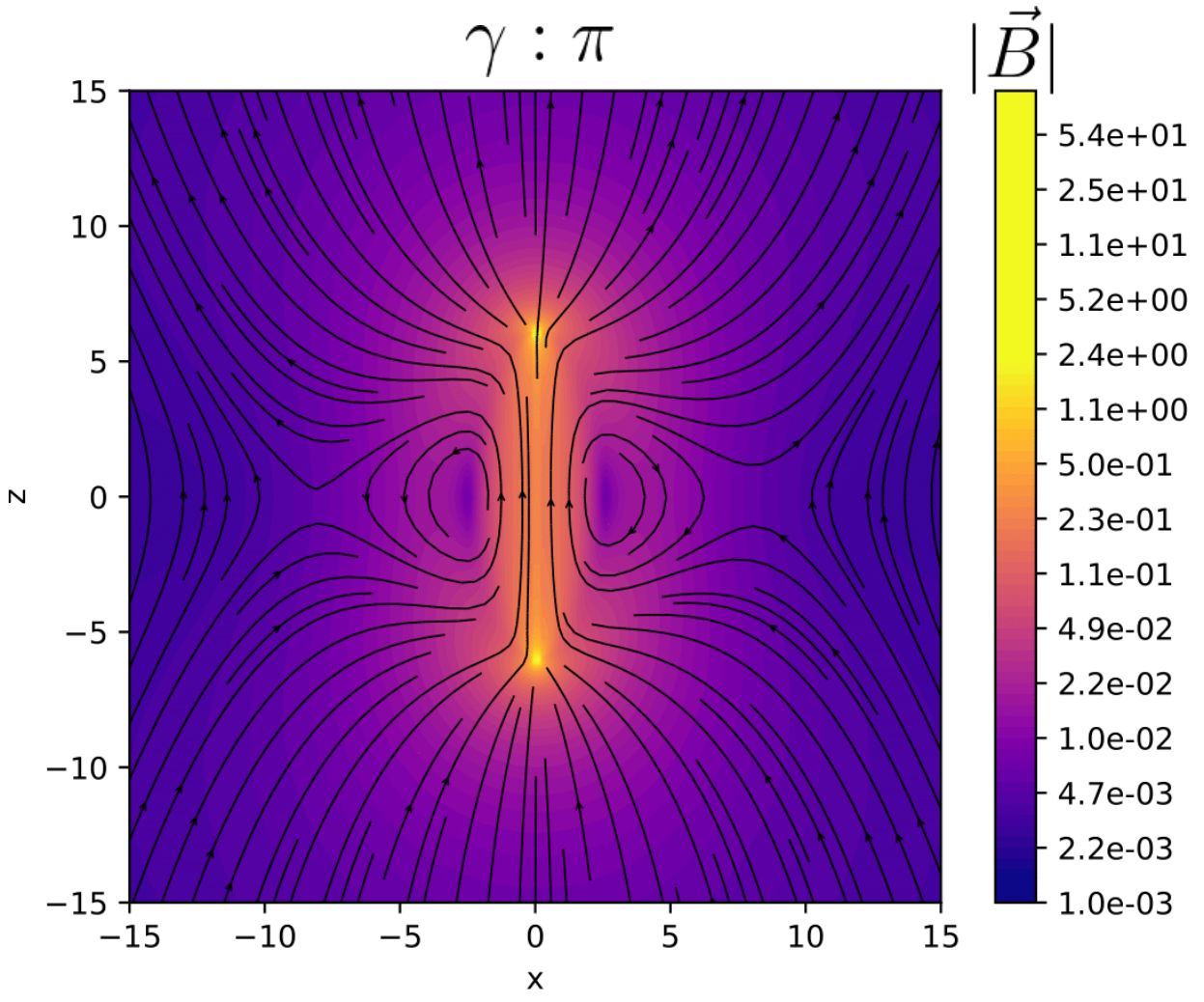


EW Sphaleron

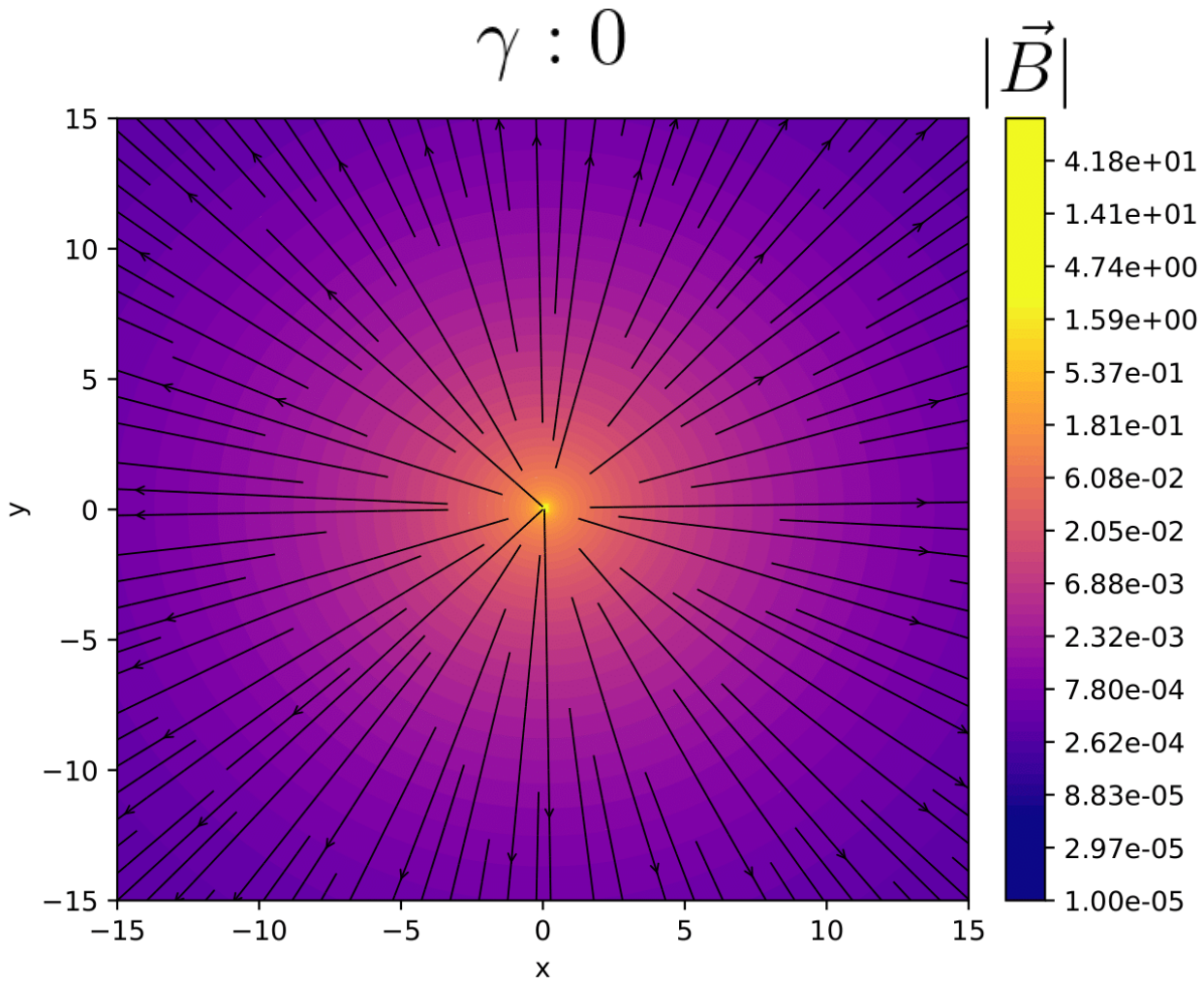
Manton, N. S.
Physical Review D
28.8 (1983): 2019.

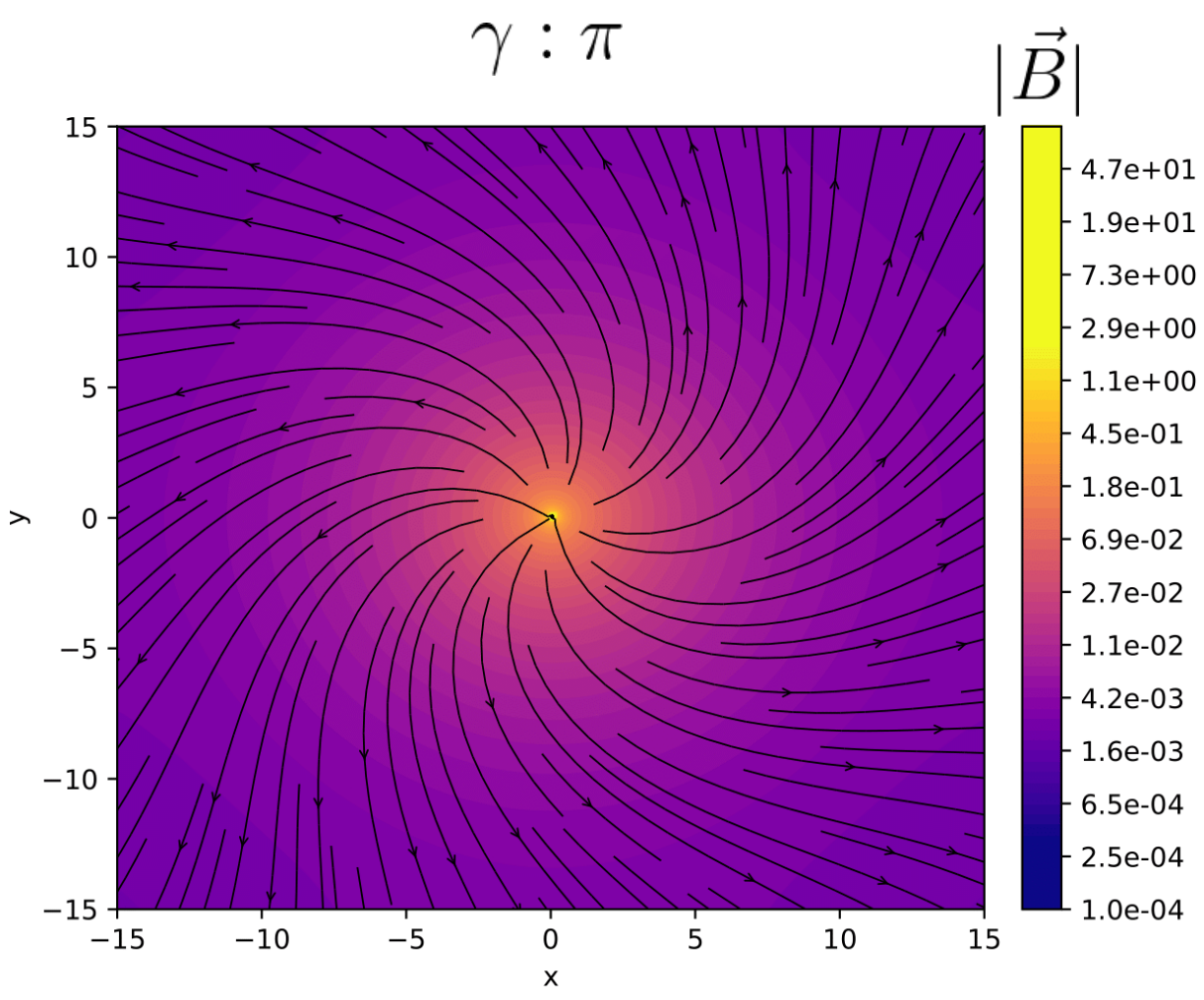
Results: Magnetic fields



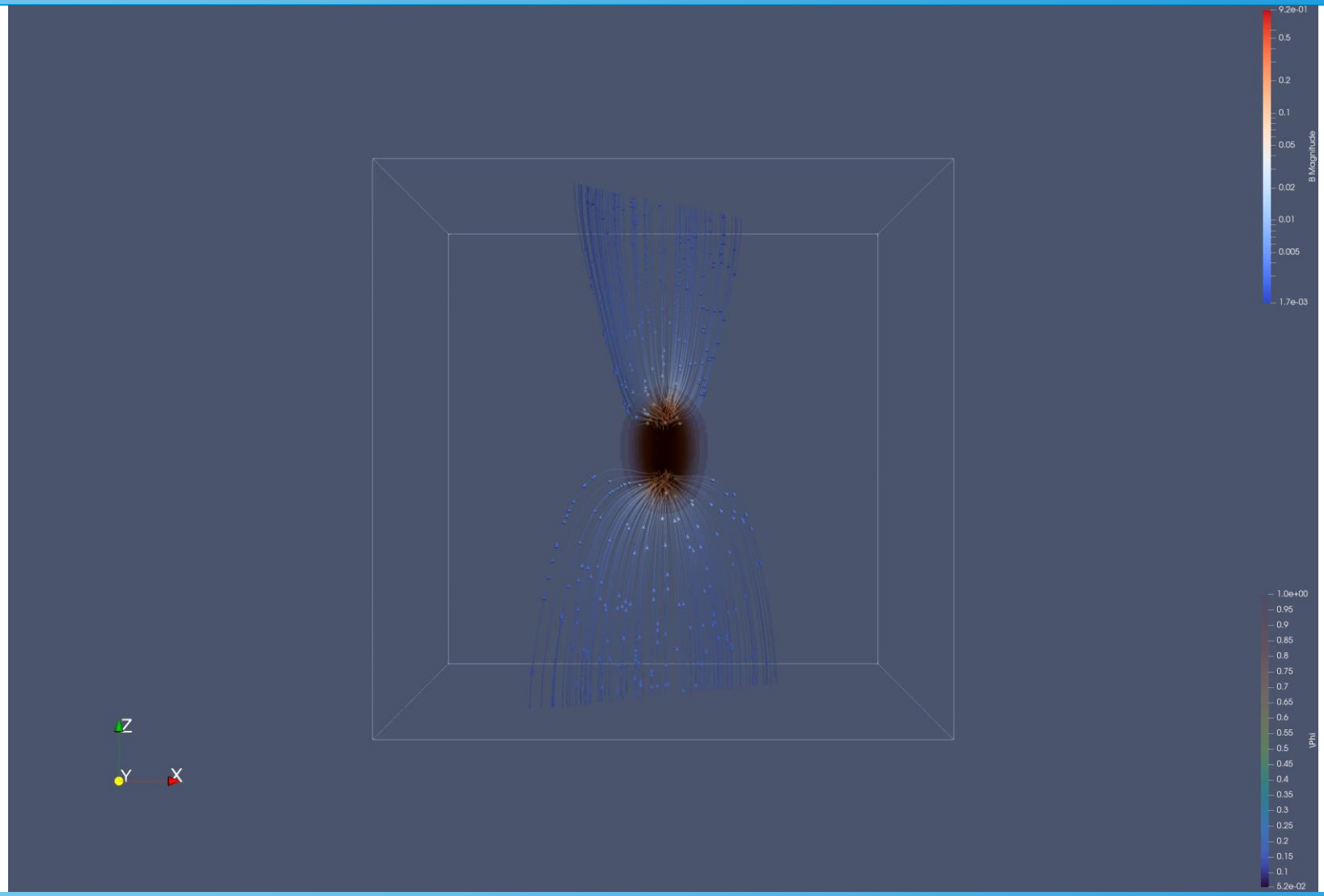


Results: Magnetic fields





Results: Magnetic fields

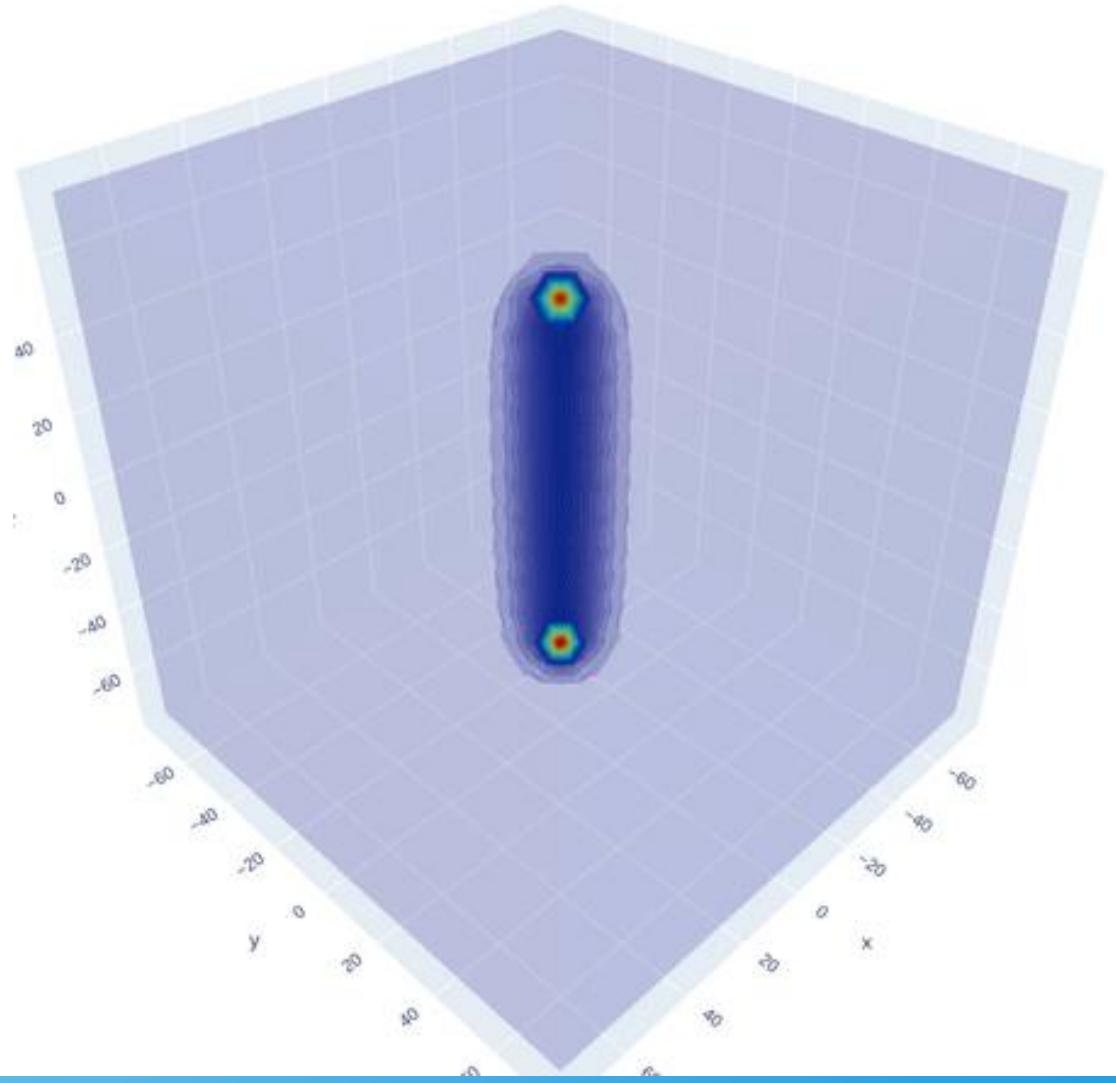


Ongoing(I) : Dumbbell Dynamics

Initial condition : Static field configuration

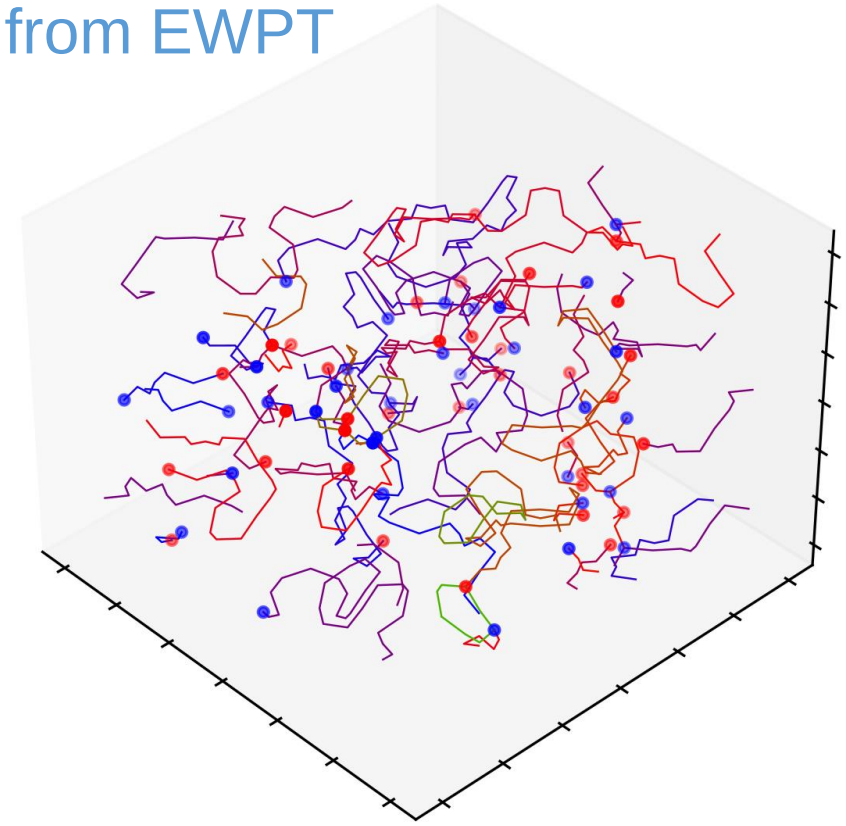
Numerical evolution: Study dynamics

One major challenge is formulating relativistic initial conditions



Ongoing(II) : Cosmological Magnetic Fields

Distribution of dumbbells from EWPT

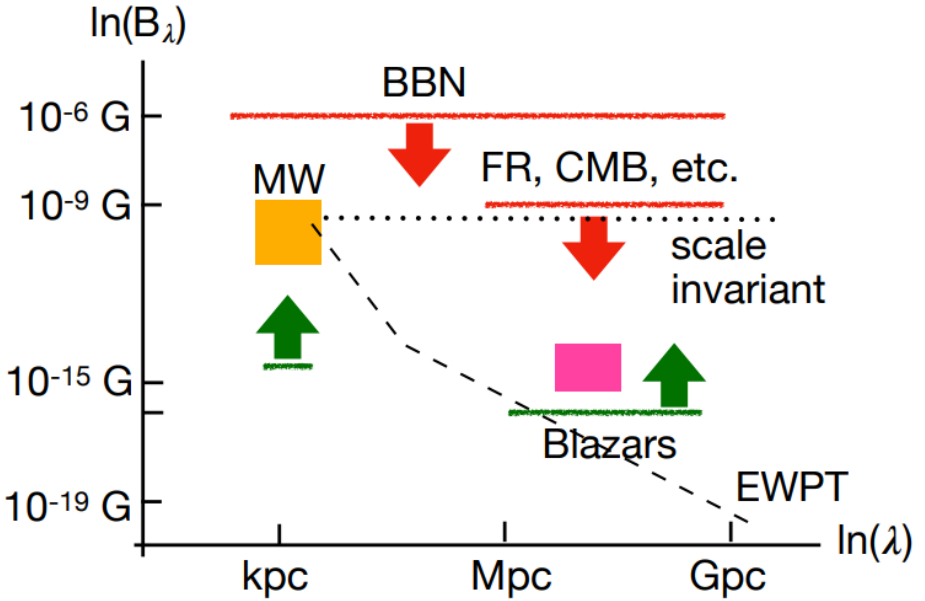


Teerthal Patel and Tanmay Vachaspati, JHEP 2022.1(2022):1-14 (arXiv:2108.05357)

MHD evolution using PENCIL

Cosmological magnetic field spectrum in the present Universe

Bounds on cosmological magnetic fields



Vachaspati, Tanmay. "Progress on cosmological magnetic fields." *Reports on progress in physics* 84.7 (2021): 074901.

PENCIL CODE : http://pencil-code.nordita.org/

Summary/Outlook

- Resolved the static dumbbell configurations
- Working on the dynamics and magnetogenesis

Possibilities to explore

- Baryogenesis
- Decay products of the annihilated dumbbell